ACM RESIDENTIAL MANUAL APPENDIX RG-2005

Appendix RG – Water Heating Calculation Method

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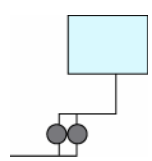
RG.1 Purpose and Scope

ACM RG documents the methods and assumptions used for calculating the hourly energy use for residential water heating systems for both the proposed design and the standard design. The hourly fuel and electricity energy use for water heating will be combined with hourly space heating and cooling energy use to come up with the hourly total fuel and electricity energy use to be factored by the hourly TDV energy multiplier. The calculation procedure applies to low-rise single family, low-rise multi-family, and high-rise residential.

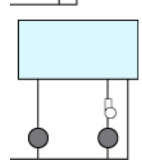
When buildings have multiple water heaters, the hourly total water heating energy use is the hourly water heating energy use summed over all water heating systems, all water heaters, and all dwelling units being modeled.

The following diagrams illustrate some of the cases that are recognized by ACM.

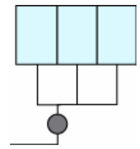
1 One distribution system with two water heaters serving a single dwelling unit.



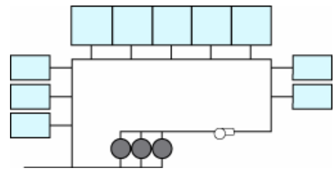
2 Two distribution systems, each with a single water heater serving a single dwelling unit.



3 One distribution system with one water heater serving multiple dwelling units.



4 Single distribution system with multiple water heaters serving multiple units.



The following rules apply to the calculation of water heating system energy use:

- One water heater type per system, e.g. no mix of gas and electric water heaters in the same system
- One solar or woodstove credit (but not both) per system

RG.2 Water Heating Systems

Water heating distribution systems may serve more than one dwelling unit and may have more than one piece of water heating equipment. The energy used by a water heating system is calculated as the sum of the energy used by each individual water heater in the system. Energy used for the whole building is calculated as the sum of the energy used by each of the water heating systems. To delineate different water heating elements several indices are used.

i Used to describe an individual dwelling unit. For instance CFAi would be the conditioned floor area of the i^{th} dwelling unit. "N" is the total number of dwelling units.

j Used to refer to the number of water heaters in a system. "M" is the total number of water heaters.

k Used to refer to a water heating system or distribution system. A building can have more than one system and each system can have more than one water heater.

RG.3 Hourly Adjusted Recovery Load

The hourly adjusted recovery load (HARL) can be calculated by Equation RG-1 through Equation RG-6.

Equation RG-1

$$HARL_k = HSEU_k \times DLM_k \times SSM_k + HRDL_k$$

This equation calculates the hourly recovery load on the water heater. The hourly adjusted recovery load (HARL) is the heat content of the water delivered at the fixture (HSEU) times the distribution loss multiplier (DLM) times the solar saving multiplier (SSM) plus the hourly recirculation losses between dwelling units (HRDL), which only occurs for multi-family central water heating systems and is zero for single family dwellings. The DLM will generally be greater than one, which means that heat is wasted as water flows from the water heater to the fixture. The DLM_k is constant for all hours with water heating end use. SSM_k is the solar savings multiplier for all solar systems. The methods for determining SSM_k for systems using SRCC OG 300 rating methods are in Section RG 3.4.1 and for systems using SRCC OG 100 rating methods are in Section RG 3.4.2.

Equation RG-2

$$HSEU_k = 8.345 \times GPH_k \times \Delta T$$

This equation calculates the hourly standard end use (HSEU) for each hour at all fixtures. The heat content of the water delivered at the fixture is the draw volume in gallons (GPH) times the temperature rise ΔT (difference between the cold water inlet temperature and the hot water supply temperature) times the heat required to elevate a gallon of water 1ºF (the 8.345 constant). GPH are calculated in a manner consistent with the

Standard Recovery Load values in the current water heating methodology (see RG.3.2.1 Pipe Insulation Eligibility Requirements).

Equation RG-3 $$\Delta T = T_S - T_{inlet}$$

Temperature difference (ºF) between cold water inlet temperature T_{inlet} and the hot water supply temperature T_s.

Equation RG-4 $$DLM_k = 1 + (SDLM_k - 1) \times DSM_k$$

This is the equation for the distribution loss multiplier. It combines two terms: the standard distribution loss multiplier (SDLM), which depends on the size of the dwelling unit and the number of stories, and the distribution system multiplier (DSM) listed in Table RG-2. For point-of-use (POU) distribution systems located in close proximity to all hot water fixtures (see RG.3.2.1 Pipe Insulation Eligibility Requirements), DLM is equal to one, e.g. there are no distribution losses.

Equation RG-5 $$SDLM_k = 1.064 + 0.000084 \times CFA_k$$

This equation gives the standard distribution loss multiplier (SDLM) for one story dwelling units, based on CFA_k (equal to the total CFA divided by the number of water heaters per dwelling unit). Multi-family SDLM's will be calculated based on the one story equation and the average CFA for all units. CFA_k is capped at 2500 ft^2 for all single and multi-family units.

Equation RG-6 $$SDLM_k = 1.023 + 0.000056 \times CFA_k$$

This equation gives the standard distribution loss multiplier (SDLM) for two and three story dwelling units, based on CFA_k (equal to the total CFA divided by the number of water heaters per dwelling unit). CFA_k is capped at 2500 ft^2 for all single and multi-family units.

Equation RG-7 $$SSM_k = 1 - SSF_k \times A$$

This equation gives the solar savings multiplier (unitless) for the kth water heating system. Equation RG-11 and Equation RG-12 provide more detail. SSF_k is the same as SF in Equation 12 (for OG 100) and as the solar collector's component of the SEF in Equation 11 (for OG 300).

where

$HARL_k$ = Hourly adjusted recovery load (Btu).

$HSEU_k$ = Hourly standard end use (Btu). This is the amount of heat delivered at the hot water fixtures relative to the cold water inlet temperature.

$HRDL_k$ = Hourly recirculation distribution loss (Btu) is the hot water energy loss in multi-family central water heating recirculation systems (See RG.3.5 Hourly Recirculation Distribution Loss for Central Water Heating Systems).HRDL is zero for all single family water heating systems and for multi-family systems with individual water heaters.

DLM_k = Distribution loss multiplier (unitless).

GPH_k = Hourly hot water consumption (gallons) of the kth system provided in RG.3.1 Hourly Hot Water Consumption (GPH).

T_s = Hot water supply temperature of 135ºF.

T_{inlet} = The cold water inlet temperature (ºF) provided in RG.3.3 Cold Water Inlet Temperature.

$SDLM_k$ = Standard distribution loss multiplier (unitless). This is calculated using Equation RG-5 for single story dwelling units and from Equation RG-6 for dwelling units with two or more stories. All multi-family projects utilize Equation RG-5 and the average dwelling unit CFA.

DSM_k = Distribution system multiplier (unitless) provided in RG.3.2 Distribution System Multiplier (DSM) within the Dwelling Unit.

CFA_k = Conditioned floor area (ft^2) capped at 2500 ft^2 for all single and multi-family units.

When a water heating system has more than one water heater, the total system load is assumed to be shared equally by each water heater. The HARL for the j^{th} water heater is then shown in the following equation.

Equation RG-8
$$HARL_j = \frac{HARL_k}{NmbrWH_k}$$

where

$NmbrWH_k$ = The number of water heaters in the k^{th} system.

RG.3.1 Hourly Hot Water Consumption (GPH)

The average daily hot water consumption GPD for a dwelling unit is equal to 21.5 gallons/day plus an additional 14 gallons per day for each 1000 ft² of conditioned floor area. Consumption is about 31.3 gallons/day for a 700 ft² apartment and 56.5 gallons/day for a 2500 ft² dwelling unit. The equation for daily hot water consumption can be expressed as follows:

Equation RG-9
$$GPD_I = 21.5 + 0.014 \times CFA_I$$

where

GPD_i = Average daily hot water consumption (gallons) of the i^{th} dwelling unit.

CFA_i = Conditioned floor area (ft²) of the i^{th} dwelling unit. When actual conditioned floor area is greater than 2500 ft², 2500 should be used in the above equation.

The hourly water consumption GPH of the k^{th} system is calculated using the average daily hot water consumption and the hourly water consumption schedule for all dwelling units served by the system.

Equation RG-10
$$GPH_k = \left(\sum_i GPD_i \right) \times SCH_m$$

where

GPH_k = Hourly hot water consumption (gallons) of the k^{th} system.

SCH_m = Fractional daily load for hour “m” from Table RG-1.

m = Hour of the day.

There are significant variations between hot water usage on weekdays and weekends, and separate schedules are used. The hourly schedules shown in Table RG-1 shall be used for calculating the hourly hot water consumption. These data are used for dwelling units of all types.

Table RG-1 Hourly Water Heating Schedules

Hour	Weekday	Weekend
1	0.014	0.018
2	0.008	0.010
3	0.009	0.009
4	0.011	0.008
5	0.020	0.015
6	0.044	0.023
7	0.089	0.026
8	0.107	0.047
9	0.089	0.077
10	0.066	0.083
11	0.052	0.074
12	0.038	0.061
13	0.036	0.051
14	0.033	0.043
15	0.032	0.039
16	0.026	0.039
17	0.042	0.052
18	0.048	0.058
19	0.052	0.056
20	0.047	0.052
21	0.042	0.047
22	0.039	0.044
23	0.036	0.040
24	0.022	0.028
Sum	1.000	1.000

RG.3.2 Distribution System Multiplier (DSM) within the Dwelling Unit

The distribution system multiplier (unitless) is an adjustment for alternative water heating distribution systems within the dwelling unit. A value of one is used for standard distribution systems defined as a "main and branch" piping system with the portion of all lines leading from the water heater to the kitchen fixtures that are equal to or greater than ¾ inch diameter insulated to a nominal R-4. Values for alternative distribution systems are given in Table RG-2.

Table RG-2 Distribution System Multipliers within a Dwelling Unit with One or More Water Heaters

Distribution System Measure	Code	DSM
Pipe Insulation (all lines)	PIA	0.90
Point of Use	POU	0.00
Pipe Insulation (kitchen lines = 3/4 inches) – Standard Case	STD	1.00
Standard pipes with no insulation	SNI	1.19
Parallel Piping	PP	1.04
Recirculation (no control)	RNC	4.52
Recirculation + timer control	RTm	3.03
Recirculation + temperature control	RTmp	3.73
Recirculation + timer/temperature	RTmTmp	2.49
Recirculation + demand control	RDmd	1.31

RG.3.2.1 Pipe Insulation Eligibility Requirements

Pipe insulation on the first five feet of hot and cold water piping from storage gas water heaters is a mandatory measure as specified in Section 150 (j) of Title 24, Part 6. Note that exceptions 3, 4 and 5 to Section 150 (j) apply to all pipe insulation that is required to meet the mandatory measure requirement or that is eligible for compliance credit.

Pipe insulation credit available if all remaining hot water lines are insulated. Insulation shall meet mandatory minimums in Section 150 (j).

Overhead Plumbing for Non-Recirculation Systems. All plumbing located in attics with a continuous minimum of 4 in. of blown insulation coverage on top of the piping will be allowed to claim the “all lines” pipe insulation credit, provided that:

1. Piping from the water heater to the attic, and
2. Piping in floor cavities or other building cavities are insulated to the minimum required for pipe insulation credit.

RG.3.2.2 Point of Use Water (POU) Water Heaters Eligibility Requirements

Current requirements apply. All hot water fixtures in the dwelling unit, with the exception of the clothes washer, must be located within 8’ (plan view) of a point of use water heater. To meet this requirement, some houses will require multiple POU units.

RG.3.2.3 Recirculation Systems Eligibility Requirements

All recirculation systems must have minimum nominal R-4 pipe insulation on all supply and return recirculation piping. Recirculation systems may not take an additional credit for pipe insulation.

The recirculation loop must be laid out to be within 8 feet (plan view) of all hot water fixtures in the house (with the exception of the clothes washer).

Approved recirculation controls include “no control”, timer control, time/temperature control, and demand control. Time/temperature control must have an operational timer initially set to operate the pump no more than 16 hours per day. Temperature control must have a temperature sensor with a minimum 20°F deadband installed on the return line.

Demand recirculation systems shall have a pump (maximum 1/8 hp), control system, and a timer or temperature sensor to turn off the pump in a period of less than 2 minutes from pump activation. Acceptable control systems include push buttons, occupancy sensors, or a flow switch at the water heater for pump initiation. At a minimum, push buttons and occupancy sensors must be located in the kitchen and in the master bathroom.

RG.3.2.4 Parallel Piping Eligibility Requirements

Each hot water fixture is individually served by a line, no larger than ½ in., originating from a central manifold located no more than 8 feet from the water heater. Fixtures, such as adjacent bathroom sinks, may be "doubled up" if fixture unit calculations in Table 6-5 of the California Plumbing Code allow.

Acceptable piping materials include copper and cross-linked polyethylene (PEX), depending upon local jurisdictions.

3/8 in. lines are acceptable, pending local code approval, provided minimum required pressures listed in the California Plumbing Code (Section 608.1) can be maintained.

Piping to the kitchen fixtures (dishwasher and sink(s)) that is equal to or greater than ¾ inch in diameter must be insulated to comply with Section 151(f)8D.

RG.3.3 Cold Water Inlet Temperature

The water inlet temperature varies monthly by climate zone and is equal to the assumed ground temperature as shown in Table RG-3.

Table RG-3 Monthly Ground Temperature (ºF)

Climate Zone	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	52.2	51.5	51.4	51.8	53.1	54.5	55.6	56.4	56.4	55.8	54.7	53.4
2	53.3	51.5	51.4	52.2	55.6	58.9	61.8	63.6	63.8	62.3	59.5	56.3
3	55.1	54.1	54.0	54.5	56.5	58.5	60.3	61.4	61.5	60.6	58.9	56.9
4	55.5	54.0	53.9	54.6	57.5	60.3	62.8	64.3	64.5	63.2	60.8	58.0
5	55.7	54.8	54.7	55.2	56.9	58.7	60.2	61.1	61.2	60.4	59.0	57.3
6	59.1	58.1	58.0	58.5	60.4	62.4	64.0	65.1	65.2	64.3	62.7	60.8
7	60.1	59.1	59.0	59.5	61.5	63.4	65.2	66.2	66.3	65.5	63.8	61.9
8	60.0	58.8	58.7	59.2	61.6	63.9	66.0	67.3	67.4	66.3	64.3	62.1
9	60.5	59.1	59.0	59.7	62.2	64.8	67.1	68.5	68.6	67.5	65.3	62.8
10	59.4	57.6	57.4	58.3	61.8	65.2	68.2	70.1	70.2	68.7	65.8	62.4
11	54.9	52.4	52.2	53.4	58.2	63.0	67.2	69.8	70.0	67.9	63.8	59.2
12	54.6	52.5	52.3	53.3	57.3	61.3	64.8	67.0	67.2	65.4	62.0	58.1
13	57.5	54.7	54.5	55.8	61.0	66.2	70.6	73.5	73.7	71.4	67.0	62.0
14	54.2	51.2	51.0	52.4	58.2	63.9	68.8	72.0	72.2	69.7	64.8	59.3
15	66.8	64.0	63.8	65.1	70.4	75.8	80.4	83.3	83.6	81.2	76.7	71.5
16	44.4	41.8	41.6	42.8	47.7	52.6	56.8	59.5	59.7	57.5	53.4	48.7

RG.3.4 Solar Savings Multiplier

Solar water heating systems and collectors are rated using information from the Solar Rating and Certification Corporation (SRCC). Two types of ratings are possible: those using SRCC OG-300 are for systems, and those using SRRC OG-100 are for collectors that will be used in built-up systems.

RG.3.4.1 Determining Solar Savings Multiplier for SRCC OG-300 Rated Systems

For solar water heating systems rated using SRCC OG-300, the solar savings multiplier SSM_k is calculated as follows:

Equation RG-11

$$SSM_k = 1 - A \times \left(1 - \left(\frac{\left(\frac{EF_{test,k} \times Q_{deltest}}{SEF_{rated,k}} \right) x \left(\frac{GPD_k}{64.3} \right) \times \left(\frac{T_s - T_{inlet}}{77} \right) + 3500 \times SYS_{type,k} \times (1 - EF_{test,k})}{Q_{deltest}} \right) \times \left(\frac{1500}{\sum_{hr=1}^{hr=24} I_{hor,hr}} \right) \right)$$

where

$EF_{test,k}$ =	Energy Factor used in SRCC OG-300 rating method for auxiliary water heater type used for rating. Two values are possible, 0.90 for a rating with an electric auxiliary water heater and 0.60 for a rating with a gas auxiliary water heater.
$Q_{deltest}$ =	The standard OG-300 energy in the hot water delivered, 41,045 Btu/day.
$SEF_{rated,k}$ =	The SEF rating as described in SRCC OG-300 and the Summary OG-300 directory for the k^{th} system.
3500 =	Average parasitic loss for a Forced Circulation system (Btu/day).
$SYS_{type,k}$ =	The OG-300 system type. There are four system types rated in OG-300. Force Circulation, Integral Collector Storage, Thermosyphon, and Self-Pumping. For Forced Circulation type systems this value is set to one. For all others, it is set to zero.
GPH_k =	Hourly hot water consumption (gallons) of the k^{th} system.
64.3 =	The standard OG-300 water draw of 64.3 gallons per day.
T_s =	Hot water supply temperature of 135ºF.
T_{inlet} =	The cold water inlet temperature (ºF) provided in Table RG-3.
77 =	Difference between Ts and T_{inlet} used in OG-300 test (ºF).
1500 =	OG-300 test daily solar insolation (Btu/hr-ft^2).
$I_{hor,hr}$ =	Hourly Horizontal solar insolation from weather data for each climate zone (Btu/hr-ft^2).
Hr =	Hour of the day from 1 through 24.
A =	An adjustment factor to account for piping losses. For Forced Circulation systems A equals 0.9 to account for collector to tank circulation piping heat loss effects. For other systems, A equals 1.0.

Eligibility Criteria

In order to use this method, the system must satisfy the applicable eligibility criteria, including:

- The collectors must face within 35 degrees of south and be tilted at a slope of at least 3:12.
- The system must be installed in the exact configuration for which it was rated, e.g. the system must have the same collectors, pumps, controls, storage tank and auxiliary system fuel type as the rated condition.
- The system must be installed according to manufacturer's instructions.
- The collectors shall be located in a position that is not shaded by adjacent buildings or trees between 9:00 AM and 3:00 PM (solar time) on December 21.

RG.3.4.2 Determining Solar Savings Multiplier for SRCC OG-100 Rated Equipment

Calculating solar hot water system energy contributions requires that the system be modeled using F-chart. Version 4.0 and all later versions can be used to calculate the percent of water heating energy delivered by the solar system. The data listed in Table RG-4 should be followed as inputs for correctly modeling solar hot water systems. If the collector type is not flat plate then the user should refer to the F-chart user manual.

Table RG-4 Prototype Solar System

F-Chart Parameter	***Value***
Collector - Number of	Enter the number of collectors in the system
Collector Area	Enter square feet of the collector listed in the SRCC directory
Collector (test slope) or FR*UL from SRCC data	Enter the value listed in the SRCC directory (I.E. -.272)
Collector (test intercept) or FR*TAU*ALPHA from SRCC data	Enter the value listed in the SRCC directory (I.E. .500 'kepstein@archenergy.com' 7)
Collector Slope	Enter degrees from horizontal
Collector Orientation	Enter orientation as an azimuth, with 0 representing north.
Collector Incident angle modifier calculation	Set to glazing.
Number of glass covers	Enter the number of the layer of transparent covers for the collector.
Collector Flow Rate/Area	Calculate or set to a default of 11 lb/hr-ft2. If calculated, determine the value by dividing the flow rate of the system by the collector area.
Collector Fluid Specific Heat	Set to 1.00 for water, 0.8 for glycol and 0.23 for air. Units in Btu/lb-F.
Collector Modify Test Values	Set to “no.”
System location	Select the climate zone the permitted building is located in.
System water volume/collector ratio	Calculate by dividing the volume of the storage tanks and collectors by the collector area. Does not include piping volume.
System Efficiency of (auxiliary) fuel usage	Set to 1 – this input does not change results.
System Daily hot water usage	Value must be calculated using Equation RG-9.
System water set temperature	Value must be set to 135.
System environmental temperature	Value must be the January value from table RG-3.
System UA of auxiliary storage tank	Calculate using the value determined with Equation RG-33 times 1/R value of the insulation.
System pipe heat loss	Assume value to be 0.
System collector-store heat exchanger	Enter Yes or No.
Tank-side flow-rate/area	Entered in lbs/hr-ft2 is the mass flow rate of water from the storage tank through the collector-storage heat exchanger divided by the total collector area. (Set this to a value larger than the collector flow rate/area in the collector parameters for an internal heat exchanger).
Heat exchanger effectiveness	Enter this ratio of the actual to maximum possible heat transfer rates for the heat exchanger located between the collector and storage unit.

F-chart will generate a Solar Fraction (SF). This value is an annual fraction of the total hot water demand met by the solar system. To adjust the SF to daily loads use Equation RG-12.

Equation RG-12

$$SSM_k = 1 - SF_k \text{ x } A$$

where

SF_k = Solar Factor (SF) derived from F-chart.

A = An adjustment factor to account for piping losses. For Forced Circulation systems A equals 0.9 to account for collector to tank circulation piping heat loss effects. For other systems, A equals 1.0.

RG.3.5 Hourly Recirculation Distribution Loss for Central Water Heating Systems

The distribution losses accounted for in the distribution system multiplier DSM are within each individual dwelling unit. Additional distribution losses occur in most multi-family dwelling units related to recirculation systems between dwelling units. These losses include losses from piping that is or could be part of a recirculation loop and branch piping to individual residential units. These losses are divided into losses to the outside air, the ground and the conditioned or semi-conditioned air within the building envelope.

Outside air includes crawl spaces, unconditioned garages, unconditioned equipment rooms, as well as actual outside air. Solar radiation gains are not included in the calculation because the impact of radiation gains is relatively minimal compared to other effects. Additionally, the differences in solar gains for the various conditions (e.g., extra insulation vs. minimum insulation) are relatively even less significant.

The ground condition includes any portion of the distribution piping that is underground, including that in or under a slab. Insulation in contact with the ground must meet all the requirements of Section 150 (j), Part 6, of Title 24.

The losses to conditioned or semi-conditioned air include losses from any distribution system piping that is in an attic space, within walls (interior, exterior or between conditioned and unconditioned spaces), within chases on the interior of the building, or within horizontal spaces between or above conditioned spaces. It does not include the pipes within the residence. The distribution piping stops at the point where it first meets the boundaries of the apartment.

These losses are added to the load accounted for in the hourly adjusted recovery load HARL, according to Equation RG-1 and calculated in the following equation.

Equation RG-13
$$HRDL_k = NL_{OA} \times UA_{OA} \times (T_s - T_{OA}) + NL_{UG} \times UA_{UG} \times (T_s - T_G) + NL_P \times UA_P$$

where

$HRDL_k$ = Hourly recirculation distribution loss (Million Btu).

T_s = Hot water supply temperature of 135°F.

T_{OA} = Hourly dry-bulb temperature of outside air (°F).

T_G = Hourly ground temperature (°F) assumed constant for each month.

NL_{OA} = Normalized load coefficient for outside air term.

NL_{UG} = Normalized load coefficient for underground term.

NL_P = Normalized load coefficient for conditioned or semi-conditioned term.

UA_{OA} = Heat loss rate of circulation pipe exposed to outside air (Btu/hr-°F).

UA_{UG} = Heat loss rate of circulation pipe buried under ground (Btu/hr-°F).

UA_P = Heat loss rate of circulation pipe in conditioned or semi-conditioned space (Btu/hr-°F).

The terms UA_{OA}, UA_{UG}, and UA_P represent the conductive area and heat loss rate for the three pipe locations. In each case the UA is a function of the pipe length, pipe diameter and pipe insulation. The program user will need to specify pipe length in each of the three locations, and specify the insulation as being either minimum (as specified in Section 150 (j), Part 6, of Title 24), or extra. Length and corresponding insulation R-value takeoffs are required for piping in each of the three locations (outdoors, underground, and conditioned or semi-conditioned space). Pipe heat loss rates (UA_{OA}, UA_{UG}, and UA_p) are then calculated for use in Equation RG-13.

The normalized load coefficients, NL_{OA}, NL_{UG}, and NL_P, are climate zone specific multipliers for the pipe losses to the outside air, ground and conditioned or semi-conditioned space, respectively. They are calculated according to the following equations:

Equation RG-14
$$NL_{OA} = \frac{C_{OA1} \times \exp\left(\frac{C_{OA2} \times UA_{OA}}{GPD_k}\right)}{WHDH_{OA}}$$

Equation RG-15

$$NL_{UG} = \frac{C_{UG1} \times \exp\left(\frac{C_{UG2} \times UA_{UG}}{GPD_k}\right)}{WHDH_{UG}}$$

Equation RG-16

$$NL_P = \frac{C_{P1} \times \exp\left(\frac{C_{P2} \times UA_P}{GPD_k}\right)}{8760}$$

where

GPD_k = The hot water consumption per day for the k[th] system. It is the sum of hot water consumption per day for all dwelling units served by the k[th] system.

$WHDH_{OA}$ = Water heating degree hours based on outside air temperature (hr-°F).

$WHDH_{UG}$ = Water heating degree hours based on ground temperature (hr-°F).

C_{OA1} , C_{OA2} = Coefficients for outside air pipe loss term.

C_{UG1} , C_{UG2} = Coefficients for underground pipe loss term.

C_{P1} , C_{P2} = coefficients for conditioned or semi-conditioned space pipe loss term.

Coefficients of C_{OA}, C_{UG}, and C_P vary by climate zones and control schemes of the circulation system. Table RG-5 lists values of these coefficients.

Table RG-5 Coefficients of C_{OA}, C_{UG} and C_P

Climate Zone	No Controls						Timer Controls					
	COA1	COA2	CUG1	CUG2	CP1	CP2	COA1	COA2	CUG1	CUG2	CP1	CP2
1	0.8933	-0.694	0.8922	-1.346	0.6259	-1.673	0.8658	-2.336	0.793	-2.062	0.6344	-4.475
2	0.854	-0.71	0.8524	-1.348	0.6433	-1.383	0.8269	-2.456	0.7572	-2.056	0.6529	-4.138
3	0.8524	-0.709	0.851	-1.355	0.6826	-1.464	0.8252	-2.37	0.7553	-2.049	0.6927	-4.438
4	0.8349	-0.688	0.8345	-1.343	0.6502	-0.706	0.8096	-2.433	0.7427	-2.071	0.667	-3.759
5	0.8494	-0.706	0.8476	-1.341	0.6873	-1.076	0.8218	-2.409	0.7536	-2.061	0.6922	-3.979
6	0.8095	-0.704	0.808	-1.341	0.7356	-1.697	0.7836	-2.367	0.718	-2.059	0.7341	-4.512
7	0.796	-0.673	0.7964	-1.349	0.735	-1.581	0.7734	-2.395	0.7082	-2.064	0.7416	-4.579
8	0.7941	-0.704	0.7925	-1.341	0.7321	-1.471	0.7683	-2.414	0.7049	-2.064	0.7333	-4.318
9	0.7853	-0.707	0.7843	-1.352	0.7208	-1.212	0.7599	-2.447	0.6971	-2.064	0.7248	-4.141
10	0.7854	-0.714	0.7843	-1.352	0.7193	-1.273	0.7595	-2.5	0.6971	-2.067	0.7188	-4.041
11	0.8137	-0.69	0.8139	-1.35	0.6149	-1.22	0.788	-2.443	0.7228	-2.051	0.6315	-4.306
12	0.8283	-0.685	0.8286	-1.349	0.6001	-0.323	0.8029	-2.451	0.7367	-2.061	0.621	-3.493
13	0.7818	-0.705	0.7813	-1.352	0.6699	-1.541	0.7564	-2.465	0.6937	-2.052	0.6752	-4.305
14	0.8094	-0.706	0.809	-1.351	0.6424	-0.866	0.784	-2.49	0.7187	-2.059	0.6515	-3.588
15	0.6759	-0.692	0.6764	-1.348	0.7514	-1.383	0.6535	-2.552	0.601	-2.061	0.7493	-4.182
16	0.9297	-0.701	0.929	-1.352	0.5231	-1.519	0.9007	-2.401	0.825	-2.053	0.5437	-4.423

Table RG-5 provides coefficients for recirculation systems where the pumps are always on and coefficients for recirculation systems that are shut off during hours 1 through 5, and hours 23 and 24 (from 10p.m. to 5a.m.). Except for systems serving only a very small number of dwelling units, there is no set of coefficients provided for the case where the circulation system does not rely on a recirculation pump. Such a system would be unlikely to supply hot water within parameters acceptable to tenants. It can be assumed that any distribution systems for supplying hot water from a central boiler or water heater require a recirculation pump and one would be supplied retroactively if not initially. For central hot water systems serving six or fewer dwelling units which have (1) less than 25' of distribution piping outdoors; (2) zero distribution piping underground; (3) no recirculation pump; and (4) insulation on distribution piping that meets the requirements of Section 150 (j) of Title 24, Part 6, the distribution system in the Standard Design and Proposed design will both assume a pump with timer controls.

$WHDH_{OA}$ is the sum of the differences between the temperature of the supply hot water (135°F) and the hourly outdoor temperature for all 8760 hours of the year. This term varies by climate zone. The values for this term are listed in Table RG-6 below. The equation uses the hourly outdoor temperatures from the weather files incorporated in the CEC approved programs.

$WHDH_{UG}$ is the sum of the differences between the supply hot water temperature (135°F) and the hourly ground temperature for all 8760 hours of the year. This term varies by climate zone. The appropriate values for this term are listed in Table RG-6 below. The equation uses the ground temperatures from the weather files incorporated in the CEC approved programs, which are assumed to be stable on a monthly basis.

Table RG-6 Water Heating Degree Hours for Outside Air and Underground

Climate Zone	$WHDH_{OA}$ (hr-°F)	$WHDH_{UG}$ (hr-°F)
1	712810	710306
2	680634	678425
3	679350	677026
4	666823	664459
5	677373	674935
6	645603	643236
7	636342	633811
8	633244	630782
9	626251	623822
10	625938	623741
11	649661	647770
12	661719	659676
13	623482	621526
14	645367	643517
15	539736	537782
16	741372	739378

UA terms are calculated using inputs provided by the user and base assumptions about the pipe diameter:
The user inputs are:

1. Pipe length in each of the three locations.
2. Insulation R value of the pipe in each location.
3. Number of stories above grade.
4. Number of apartment units.

The total length of the circulation pipe is calculated, along with the fraction in each location (PF_{OA}, PF_{UG} and PF_P). The square feet of surface area is calculated according to the following equation:

Equation RG-17

$$SF_{total} = LF_{total} \times Dia \times \pi$$

where

SF_{Total} = The total surface area of the circulation piping, square feet.

LF_{Total} = The total lineal feet of all circulation piping, feet.Dia = Average calculated (Equation RG-18) diameter of pipe in circulation piping, feet.

π = Pythagorean constant (ratio of perimeter to diameter), 3.1416

The average diameter of hot water piping, Dia, is calculated by the following equation:

Equation RG-18
$$Dia = 0.045 \times \left(\frac{LF_{Total}}{\Delta P}\right)^{0.21} \times (AptGPM)^{0.37} \times \frac{(NumApts)^{0.37}}{1.37}$$

The terms of the above equation are described below. The total system pressure drop, ΔP, given in psf is calculated in Equation RG-19.

Equation RG-19
$$\Delta P = \left[P_{meter} - 4.3 \times (NumStories - 1) - 15\right] \times 144$$

where

P_{meter} = Water system supply pressure, (60 psig by assumption).

NumStories = Number of stories above grade, (but enter "4" if more than 4 stories).

Equation RG-20
$$AptGPM = \frac{1.765 \times (12 \times NumApts)^{0.687}}{NumApts}$$

NumApts = Number of apartments in the building served by the hot water system, apts

The UA for each of the three locations is derived as a function of the fraction of the total pipe in that location times a factor that represents the conductivity of the standard (minimum) insulation or the "extra" insulation condition. The following two equations provide the alternate equations for the two insulation cases. The factors do not vary by location so the equations for the other two locations are of exactly the same form, varying only by the fraction of pipe in that location.

The benefits of additional insulation shall be calculated as required in Section 150 (j) of Title 24. The insulation value of the ground and of protective coverings may not be used for achieving the minimum insulation values required by Section 150 (j). To qualify as extra insulation, the insulation must be at least 1/2" thicker than the insulation required by Section 150 (j).

Equation RG-21 For extra insulation for the standard design:
$$UA_i = SF_{Total} \times PF_i \times \left(\frac{k}{Radius \times Ln\left(\frac{Radius + Thick + 0.5}{Radius}\right)}\right)$$

Equation RG-22 For minimum insulation:
$$UA_i = SF_{Total} \times PF_i \times \left(\frac{k}{Radius \times Ln\left(\frac{Radius + Thick}{Radius}\right)}\right)$$

where

i = Subscript indicating pipe location OA = outside, UG = underground, P = conditioned or semi-conditioned space

PF_i = Pipe fraction in i^{th} location, no units

k = Insulation conductivity, (assumed 0.25 Btu inch/h·sf·°F)

Radius = Average pipe radius in inches, (Radius = Dia x 12 / 2), inches

Thick = Base case insulation thickness, Thick = 1 if average pipe radius is less than or equal to 2";Thick = 1.5 if radius is greater than 2", inches

RG.4 Energy Use of Individual Water Heaters

Once the hourly adjusted recovery load is determined for each water heater, the energy use for each water heater is calculated as described below.

RG.4.1 Small[1] Gas, Oil, or Electric Storage and Heat Pump Water Heaters

The hourly energy use of storage gas, storage electric and heat pump water heaters is given by the following equation.

Equation RG-23

$$WHEU_j = \left[\frac{HARL_j \times HPAF_j}{LDEF_j}\right] WSAF_j$$

where

$WHEU_j$ = Hourly energy use of the water heater (Btu for fuel or kWh for electric), adjusted for tank insulation and wood stove boilers.

$HARL_j$ = Hourly adjusted recovery load (Btu).

$HPAF_j$ = Heat pump adjustment factor from the table below based on climate zone. This value is one for storage gas, storage oil and storage electric water heaters.

The energy consumption of one or more independent hot water storage tanks that are not rated as water heaters is calculated by substituting $xHARL_j$ for $HARL_j$ where $xHARL_j$ is defined in Section __.

Table RG-7 Heat Pump Adjustment Factors

Climate Zone	Heat Pump Adjustment Factor	Climate Zone	Heat Pump Adjustment Factor
1	1.040	9	0.920
2	0.990	10	0.920
3	0.990	11	0.920
4	1.070	12	1.070
5	1.070	13	0.920
6	0.920	14	1.040
7	0.920	15	0.920
8	0.920	16	1.500

$LDEF_j$ = The hourly load dependent energy factor (LDEF) is given by the following equation. This equation adjusts the standard EF for different load conditions.

Equation RG-24

$$LDEF_j = e \times \left(\ln\left(\frac{HARL_j \times 24}{1000}\right)(a \times EF_j + b) + (c \times EF_j + d) \right)$$

where

a,b,c,d,e = Coefficients from the table below based on the water heater type.

[1] "Small water heater" means a water heater that is a gas storage water heater with an input of 75,000 Btu per hour or less, an oil storage water heater with an input of 105,000 Btu per hour or less, an electric storage water heater with an input of 12 kW or less, a gas instantaneous water heater with an input of 200,000 Btu per hour or less, an oil instantaneous water heater with an input of 210,000 Btu 1602 per hour or less, an electric instantaneous water heater with an input of 12 kW or less, or a heat pump water heater rated at 24 amps or less.

Table RG-8 LDEF Coefficients

Coefficient	Storage Gas	Storage Electric	Heat Pump
a	-0.098311	-0.91263	0.44189
b	0.240182	0.94278	-0.28361
c	1.356491	4.31687	-0.71673
d	-0.872446	-3.42732	1.13480
e	0.946	0.976	0.947

Note: EF for storage gas water heaters under 20 gallons must be assumed to be 0.58 unless the manufacturer has voluntarily reported an actual EF to the California Energy Commission. As of April 2003, manufacturers of this equipment are no longer required to do so.

EFj = Energy factor of the water heater (unitless). This is based on the DOE test procedure.

WSAFj = Wood stove boiler adjustment factor for the j^{th} water heating system. This is given in Section RG.4.6 Wood Stove Adjustment Factors. This is an optional capability and is set to 1.00 for ACMs without wood stove boiler modeling capability.

RG.4.2 Small Gas or Oil Instantaneous[2]

The hourly energy use for instantaneous gas or oil water heaters is given by the following equations.

Equation RG-25

$$WHEU_j = \left(\frac{HARL_j}{EF_j} + PILOT_j \right) \times WSAF_j$$

where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu), adjusted for wood stove boilers.

$HARL_j$ = Hourly adjusted recovery load.

EF_j = Energy factor from the DOE test procedure (unitless). This is taken from manufacturers literature or from the CEC Appliance Database.

$PILOT_j$ = Energy consumption of the pilot light (Btu/h). Default if no information provided in manufacturer's literature or CEC Appliance Database is 500 Btu/hr.

$WSAF_j$ = Wood stove boiler adjustment factor for the j^{th} water heating system. This is an optional capability and is set to 1.00 for ACMs without wood stove boiler modeling capability.

RG.4.3 Small Electric Instantaneous

The hourly energy use for instantaneous electric water heaters is given by the following equation.

$$WHEU_{j,elec} = \frac{HARL_j \times WSAF_j}{3413 \times EF_j}$$

Equation RG-26

where

$WHEU_{j,\ elec}$ = Hourly electricity energy use of the water heater (kWh), adjusted for wood stove boilers.

$HARL_j$ = Hourly adjusted recovery load.

EF_j = Energy factor from DOE test procedure (unitless).

2 "Instantaneous water heater" means a water heater that has an input rating of at least 4,000 Btu per hour per gallon of stored water.

$WSAF_j$ = Wood stove boiler adjustment factor for the j^{th} water heating system. This is an optional capability and is set to 1.00 for ACMs without wood stove boiler modeling capability.

RG.4.4 Large[3] Gas or Oil Storage. Large Instantaneous, Indirect Gas and Hot Water Supply Boilers[4].

Energy use for large storage gas and indirect gas water heaters is given by the following equations. Note: large storage gas water heaters are defined as any gas storage water heater with a minimum input rate of 75,000 Btu/h.

Equation RG-27

$$WHEU_j = \left[\frac{HARL_j + HJL_j}{EFF_j \times EAF_j} + PILOT_j\right] \times WSAF_j$$

where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu), adjusted for tank insulation and wood stove boilers.

$HARL_j$ = Hourly adjusted recovery load. For independent hot water storage tank(s) substitute $xHARL_j$ from Section RG.4.9 Independent Hot Water Storage Tanks for $HARL_j$.

HJL_j = Hourly jacket loss (Btu/h) for tank rated with the water heater. For nonstorage water heaters and boilers set this term to zero. To account for independent hot water storage tanks substitute $xHARL_j$ (from Section RG.4.9 Independent Hot Water Storage Tanks) for $HARL_j$ storage tanks

EFF_j = Efficiency (fraction, not %). To be taken from CEC Appliance Database or from manufacturers literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

EAF_j = Efficiency adjustment factor (unitless). This value is 1.0 for large storage gas water heaters and 0.98 for indirect gas water heaters.

$PILOT_j$ = Pilot light energy (Btu/h) for large instantaneous. For large instantaneous water heaters, and hot water supply boilers the default is 750 Btu/hr if no information is provided in manufacturer's literature or CEC Appliance Database. For storage type water heaters the default is zero.

$WSAF_j$ = Wood stove boiler adjustment factor for the j^{th} water heating system. This is an optional capability and is set to 1.00 for ACMs without wood stove boiler modeling capability.

RG.4.5 Large Electric Storage

Energy use for large storage electric water heaters is given by the following equation.

Equation RG-28

$$WHEU_{j,elec} = \left[\frac{HARL_j + HJL_j}{0.85 \times 3.413}\right] \times WSAF_J$$

where

$WHEU_{j,\ elec}$ = Hourly electricity energy use of the water heater (kWh), adjusted for wood stove boilers.

$HARL_j$ = Hourly adjusted recovery load.

3 "Large water heater" means a water heater that is not a small water heater.

4 "Hot water supply boiler" means an appliance for supplying hot water for purposes other than space heating or pool heating.

HJL_j = Hourly jacket loss (Btu/h) for the tank rated with the heater.

$WSAF_j$ = Wood stove boiler adjustment factor for the j^{th} water heating system. This is an optional capability and is set to 1.00 for ACMs without wood stove boiler modeling capability.

RG.4.6 Wood Stove Adjustment Factors

This is an optional capability and the Wood Stove Boiler Adjustment Factor is set to 1.00 for ACMs without wood stove boiler modeling capability. The wood stove adjustment factor (unitless) reduces water heating energy to account for the heat contribution of wood stove boilers. This multiplier is taken from the table below, based on climate zone and whether the wood stove boiler has a recirculation pump. The inclusion of this factor and its relevant input parameters is an optional capability for ACMs. However, when this optional capability is implemented the algorithms and procedures given below must be used.

Table RG-9 Wood Stove Adjustment Factors

Climate Zone	Wood Stoves with Pumps	Wood Stoves without Pumps
1	0.775	0.750
2	0.775	0.750
3	0.775	0.750
4	0.865	0.850
5	0.865	0.850
6	0.910	0.900
7	0.910	0.900
8	0.955	0.950
9	0.910	0.900
10	0.955	0.950
11	0.910	0.900
12	0.865	0.850
13	0.910	0.900
14	0.910	0.900
15	1.000	1.000
16	0.730	0.700

RG.4.7 Jacket Loss

The hourly jacket loss for large storage gas and indirect gas water heaters is calculated as

Equation RG-29

$$HJL_J = \frac{TSA_j \times \Delta TS}{RTI_j + REI_j} + FTL_j$$

where

TSA_j = Tank surface area (ft^2).

FTL_j = Fitting losses. This is a constant 61.4 Btu/h.

REI_j = R-value of exterior insulating wrap.

RTI_j = Calculated R-value of insulation internal to water heater.

For water heaters with standby loss rated in percent heat content of the stored water:

Equation RG-30

$$RTI_j = \frac{TSA_j \times \Delta TS}{\left[\left(8.345 \times VOL_j \times SBL_j \times \Delta T\right) - FTL_j - PILOT_j\right] \times EFF_j \times EAF_j}$$

For water heaters with standby loss rated in Btu/hr:

Equation RG-31

$$RTI_j = \frac{TSA_j \times \Delta TS}{\left[\left(SBE_j \times \left(\frac{\Delta TS}{60}\right)\right) - FTL_j - PILOT_j\right] \times EFF_j \times EAF_j}$$

SBE_j = Standby loss expressed in Btu/hr from the CEC Appliance Database or from manufacturer's literature.

SBL_j = Standby loss expressed as a fraction of the heat content of the stored water lost per hour from the CEC Appliance Database or from manufacturer's literature.

$PILOT_j$ = Pilot light energy (Btu/h). If no information is provided in manufacturer's literature or CEC Appliance Database default to zero.

ΔTS = Temperature difference between ambient surrounding water heater and hot water supply temperature (ºF). Hot water supply temperature shall be 135ºF. For water heaters located inside conditioned space use 75ºF for the ambient temperature. For water heaters located in outside conditions use hourly dry bulb temperature ambient.

The hourly jacket loss for large storage electric heaters is calculated as:

Equation RG-32

$$HJL_i = \frac{TSA \times \Delta T}{\left(RTI_j + REI_j\right)}$$

(same definitions as above)

RTIj = Calculated R-value of insulation internal to water heater.

REIj = R-value of exterior insulating wrap.

Where the calculated insulation R-value RTI_j is calculated by:

Equation RG33

$$RTI_j = \frac{\left(TSA_j \times \Delta TS\right)}{\left[\left(8.345 \times VOL_j \times SBL_j \times \Delta TS\right) \times EFF_j\right]}$$

where

SBLj = Standby loss expressed in percent heat content loss of the stored water, from manufacturer's data.

EFFj = Efficiency, from manufacturer's data.

RG.4.8 Tank Surface Area

Tank surface area (TSA) is used to calculate the hourly jacket loss (HJL) for large storage gas, indirect gas water heaters, and large storage electric water heaters. TSA is given in the following equation as a function of the tank volume.

Equation RG-34

$$TSA_j = e \times \left(f \times VOL_j^{0.33} + g\right)^2$$

where

VOL_j = Tank capacity (gallons).

e, f, g = Coefficients given in the following table.

Table RG-10 Coefficients for Calculating Tank Surface Areas

Coefficient	Storage Gas	Large Storage Gas and Indirect Gas	Storage Electric and Heat Pumps
E	0.00793	0.01130	0.01010
F	15.67	11.8	11.8
G	1.9	5.0	5.0

RG.4.9 Independent Hot Water Storage Tanks

The additional loads due to independent hot water storage tanks which are not rated as water heaters is calculated by adding the sum of the jacket losses for one or more of these tanks to the Hourly Adjusted Recovery Load for the jth water heater and substituting $xHARL_j$ for $HARL_j$ in the appropriate equation above for the jth water heater:

Equation RG-35

$$xHARL_j = HARL_j + \sum_k HJL_{j,k}$$

where

$xHARL_j$ = Hourly Adjusted Recovery Load for the jth water heater plus the load due to independent hot water storage tanks serving the jth hot water heater.

$HARL_j$ = Hourly Adjusted Recovery Load for the jth water heater as defined by Equation RG-1.

$HJL_{j,k}$ = Hourly Jacket Loss of the kth independent hot water storage tank serving the jth water heater.

The hourly jacket loss, HJL is calculated per RG.4.7 Jacket Loss using Equation RG-29. When the Standby Loss for the tank is not available or not listed, RTIj may be set at zero and the total tank insulation may be entered for REI. The minimum value of REI allowed by the ACM shall be a 0.68 still air film.

RG.5 Electricity Use for Circulation Pumping

For single-family recirculation systems, hourly pumping energy is fixed as shown in following table.

Table RG-11 Single Family Recirculation Energy Use (kWh) by Hour of Day

Hour	Uncontrolled Recirculation	Timer Control	Temperature Control	Timer/Temp Control	Demand Recirculation
1	0.040	0	0.0061	0	0.0010
2	0.040	0	0.0061	0	0.0005
3	0.040	0	0.0061	0	0.0006
4	0.040	0	0.0061	0	0.0006
5	0.040	0	0.0061	0	0.0012
6	0.040	0	0.0061	0	0.0024
7	0.040	0.040	0.0061	0.0061	0.0045
8	0.040	0.040	0.0061	0.0061	0.0057
9	0.040	0.040	0.0061	0.0061	0.0054
10	0.040	0.040	0.0061	0.0061	0.0045
11	0.040	0.040	0.0061	0.0061	0.0037
12	0.040	0.040	0.0061	0.0061	0.0028
13	0.040	0.040	0.0061	0.0061	0.0025
14	0.040	0.040	0.0061	0.0061	0.0023
15	0.040	0.040	0.0061	0.0061	0.0021
16	0.040	0.040	0.0061	0.0061	0.0019
17	0.040	0.040	0.0061	0.0061	0.0028
18	0.040	0.040	0.0061	0.0061	0.0032
19	0.040	0.040	0.0061	0.0061	0.0033
20	0.040	0.040	0.0061	0.0061	0.0031
21	0.040	0.040	0.0061	0.0061	0.0027
22	0.040	0.040	0.0061	0.0061	0.0025
23	0.040	0	0.0061	0	0.0023
24	0.040	0	0.0061	0	0.0015
Annual Total	350	234	53	35	23

Multi-family recirculation systems may have vastly different pump sizes and is therefore calculated based on the installed pump size. The hourly electricity use for pumping (HEUP) water in the circulation loop can be calculated by the hourly pumping schedule and the power of the pump motor as in the following equation.

Equation RG-36

$$HEUP_k = \frac{0.746 \times PUMP_k \times SCH_{k,m,}}{\eta_k}$$

where

$HEUP_k$ = Hourly electricity use for the circulation pump (kWh).

$PUMP_k$ = Pump brake horsepower (bhp).

$?_k$ = Pump motor efficiency.

$SCH_{k,m}$ = Operating schedule of the circulation pump. For 24-hour operation (no controls), the value is always 1. For timer controls, the value is 1 when pump is on and 0 otherwise. The pump is assumed off from 10 p.m. to 5 a.m. and on for the remaining hours.